CHAPTER 10: ELECTRICITY IN THE BOILER

10- ELECTRICITY APPLIED TO THE BOILER

Automatic controls, alarms, water feed pumps, fuel pumps, fans (forced and induced draft), etc., are normally (nowadays) based on the use of electricity.

In the past, boilers used steam power and human control.

Electricity can be defined as the use of the phenomena caused by the flow of electrons in conductive and semiconducting materials.

There are materials through which electricity flows: Conductors (gold, silver, copper, aluminum, iron—that is, almost all metals, as well as water containing ionizing salts, etc.)

They are used to transport electricity and harness its power: conductors or electrical cables.

Materials in which electricity flows with difficulty are: Semiconductors (metalloids or materials that barely conduct electrons due to impurities of other materials: silicon, germanium, etc. They are used in electronics to manufacture transistors, diodes, "chips", etc.).

Those through which electrons do not flow are: Insulators (they do not allow the passage of electrons; they serve to "isolate" or prevent the "loss or escape" of electrons from the materials that conduct them: the "sheathing" of cables, insulating tape, plastics, micarta, insulating varnish, dry wood, etc.).

Voltage (potential difference): This is the force with which these electrons are "propelled" (just as the height of a water tank above a tap determines the "pressure" or "force" with which the water flows).

It is measured with a voltmeter, and the unit used is the volt. Amperage (current or intensity): This is the "amount of electricity or electrons" that passes through a conductor in a given time (just as if

we were measuring the liters per second of water flowing from a tap). It is measured with an ammeter, and its unit is the ampere.

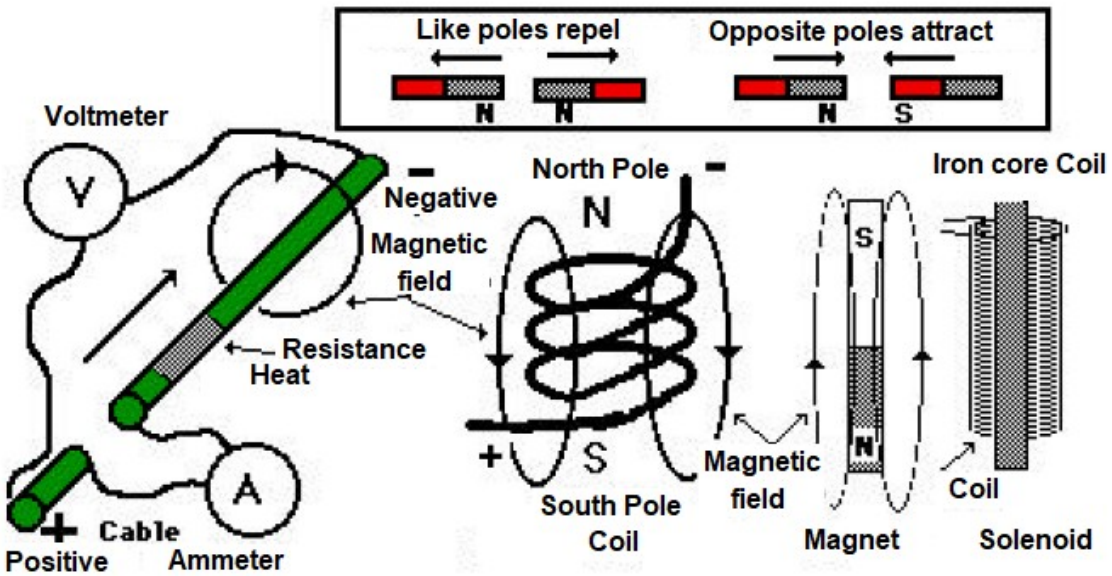
Multiplying the two previous values gives the result of power, which is measured in watts (w) or kilowatts (kW = 1000 watts). This gives us an idea of the work capacity that a supply of a given voltage and amperage can perform.

The electric current that has a fixed direction of circulation: from positive to negative (+ to -, when in reality the electrons go from negative to positive), this current can be direct or alternating (in the first the electrons always go in the same direction: a car battery, cell, etc.).

In the second, the electrons go one way for one period of time and the other way around for another period: like the current supplied by an alternator or the current supplied by UTE, which is 50 cycles per second, that is, it changes direction 50 times per second to each side).

When we talk about a power supply, to define it we must specify in each case: if it is direct current (DC), the voltage and the available or desired amperage.

But if we are talking about alternating current (AC), we must specify the voltage, the amperage, and also the frequency (cycles or periods per second, or Hertz).



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Useful Properties of Electricity:

When an electric current passes through a conductive wire, two important things occur: heat and a magnetic field.

The heat is the result of electrons colliding with the atoms that make up the wire. This heat is greater the more electrons pass through the wire and the greater the resistance the wire offers to the flow of electrons: this property is called the electrical resistance of conductive materials.

Electrical resistance is a property of each material, but it also depends on the wire's cross-section and length.

A good conductor has low resistance. Listing materials from lowest to highest specific resistance, we have: gold, silver, copper, aluminum, iron, etc.

A thick wire has lower resistance than a thin wire, and a long wire has higher resistance than a short one of the same cross-section.

This electrical resistance is detrimental to the transmission of electricity or its use in magnetic applications (solenoids, motors, etc.), but it is useful for transforming electrical energy into heat (water heaters, oil heaters, electric boilers, incandescent lights, etc.).

Electrical cables are generally made of copper (or aluminum in some cases). They must be thick enough (with a cross-sectional area) to avoid losing power or voltage when carrying current from one place to another, and the further apart the cable is, the thicker it needs to be.

This is governed by Ohm's Law, which states that the amperage (A) flowing through a conductor is greater with higher voltage (V) and less with higher resistance (R): $A = V/R$.

Electricity (the flow of electrons) also causes a magnetic field to form (a magnet is a metal: iron, which forms a magnetic field with a stationary north and south pole. We know that opposite poles attract each other in magnets and that they also attract magnetic materials

like iron, which, when magnetized, behave like magnets).

This magnetic field becomes stronger as the current increases, and we can increase it by winding the wire to concentrate the fields. We can further increase it by placing a material that is easily magnetized, such as iron, at the center of the wire.

When we have a wire wound around a coil to increase its magnetic field, it's called a coil, and when this coil has a core or central iron element, it's called a solenoid.

There are magnetic materials, meaning materials that are easily magnetized, like iron; there are materials that are not magnetic or only slightly or not at all magnetizable, such as stainless steel, copper, etc.

The magnetic field formed can be continuous or alternating, depending on the current that creates it. These fields have many useful applications; they operate solenoid valves, contactor solenoids, electric motors, and so on.

Electric motors operate by the rotation (or attraction and repulsion) of magnetic fields generated by the current in their windings. Conversely, when a conductor is cut by a moving magnetic field or subjected to a changing magnetic field, an electric current is induced. This applies to generators, alternators, transformers, and so on.

Safety in the use of electrical current:

Electric current must be handled with great care and respect, as at a certain voltage it can kill a person (sometimes with voltages below 100 volts, alternating or direct current, a small electrical current passing through the human heart (a few milliamps) can stop it by causing a muscle contraction).

The voltage required for this to be sufficient depends on the conditions of the "electric shock"; a person who is wet or wearing shoes with hard soles is more vulnerable, etc.

Electrical Safety: At high voltages, when current flows through the human body, it not only causes contraction but

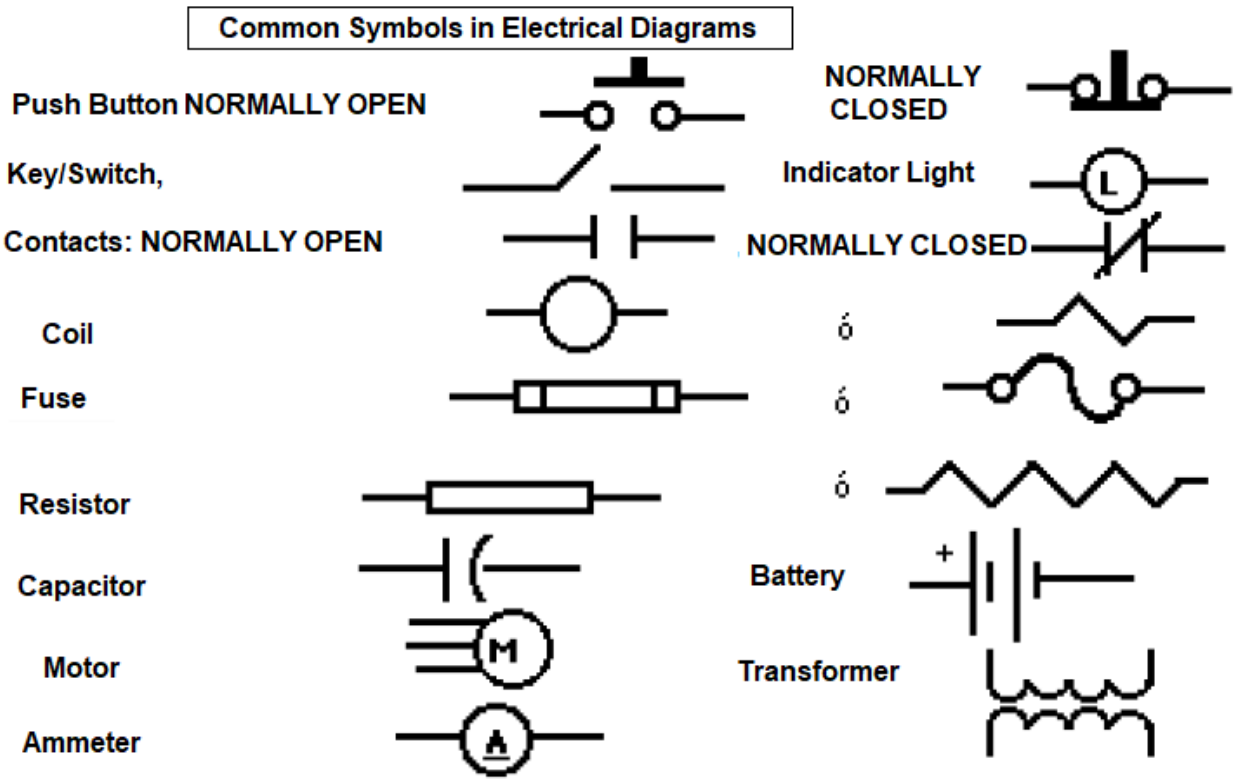
also burns.

Even at low voltages, a short circuit can be dangerous. This occurs when two current poles are connected, and because the resistance is so low, it causes a "heat explosion" (due to the high current) that can burn us. (For example, connecting two battery poles with a thick wire or a metal tool produces such a high current that it creates a spark that burns and can cause the battery to explode due to the release of gases and heat.)

Electricity must be handled with knowledge and not as a "touch-and-feel" to see what happens, since mistakes can not only be fatal, but can also cause failures that can be very costly.

To work with electricity, you must also be in good physical condition; that is, wear shoes with insulating rubber soles and be dry.

Completely cut off the power (turn off switches or remove fuses) if you are working on a circuit (put up a sign to prevent anyone from reconnecting it while you are working), avoid short-circuiting (connecting two wires or elements of different polarity with a jumper that easily conducts current), and use the appropriate tools (pliers and screwdrivers with the correct insulation).



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Electrical Circuit Components of Boilers:
Electrical circuits are drawn in two ways:

a) Schematic drawing: This is the simplest way to understand how the circuit works. Terminals are omitted, and connections are made directly between components.

b) Diagrammatic drawing or the circuit "wiring": This shows the position of each component on the panel, the terminals, and the position of each interconnecting wire.

(This diagram allows us to "wire" the components to assemble the panel or trace the wires to find faults.)

Both diagrams should always be readily available on the boiler's control panel. To do this, we need to know the symbols used in the drawings (there are several ways to represent a component depending on the country of origin; we have included some examples).

The fuse:

This component serves to limit or prevent excessive electrical current from passing through a wire, causing it to burn out. It also protects the circuit or equipment supplying the current. (It is the first component we encounter when connecting any electrical load).

It is made of a thin conductor that "heats up" when current passes through it. If the current exceeds a certain value, the heat "melts" the conductor, cutting it. (The conductor is normally immersed in insulating powder so that the heat does not dissipate too quickly). It acts in cases of both overload (I > In, for example, double) and overcurrent (I >> In, for example, 10 times).

There are fast-acting and slow-acting fuses (or fuses in between).

Nowadays, modern thermomagnetic circuit breakers are used; where "I >" is the thermal element that acts in case of overload, and where "I >>" is the magnetic element that acts in case of overcurrent.

Fast-trip circuit breakers are those that barely exceed the current limit: they "trip" and are used to protect control and lighting circuits.

Slow-trip circuit breakers allow the current to momentarily exceed the set value: they are used to protect circuits connected to electric motors, since these draw a lot of current when starting. They are identified by class or type: gG, gL, or aM with different curves.

gG for general distribution,
gL for pure cable protection,
aM for motor feeders

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Whenever a fuse blows, the cause of the short circuit or overload must be investigated, and the correct type and rating of fuse must be replaced. Do not use fuses or wires of a higher rating (this risks damaging the entire circuit).

Fuses come in various physical forms: cartridges, plugs, etc. They must make good contact; otherwise, they will heat up and melt even without an overload (this is the first component to inspect when a fault occurs, but before replacing it, investigate why it blew).

Thermal circuit breaker (I > In):

This device connects or disconnects an electrical circuit like a light switch. It has a thermal element for each wire it connects. When current flows through it, this element heats a bimetallic strip that acts as a trip mechanism, opening the contacts if the amperage exceeds a certain value (overload).

When an overload (high amperage) occurs, this circuit breaker trips. To reset it, you must wait a while for it to cool down before pressing a button or pushing the reset lever in reverse to reset the circuit breaker so the switch can close its contacts again.

In some cases, it does not replace a fuse, as it does not protect against short circuits because it takes a relatively long time to trip.

Thermal-magnetic circuit breaker (I >> In):

This circuit breaker is similar to the previous one, but in addition to tripping on overload, it also trips on short circuit (quickly). Each connecting wire has a magnetic trip (solenoid trip) that, upon detecting a rapid overload, triggers a mechanical trip.

Once it has "tripped due to overload," it must be reset, waiting, if necessary, for its bimetallic elements to cool down if they have heated up.

It is more complete than the previous circuit breaker and serves as the main switch for a panel that powers controls and electric motors. On its own, without a thermal element, it does not completely replace fuses; a fuse is always a simple and reliable protection.

The thermal-magnetic circuit breaker (I > and I >> protection elements) does replace a fuse.

Contactor or "starter":

this term can be used to describe the "switch" or switch that supplies power to an electric motor. It typically consists of a set of fixed contacts connected by moving contacts, which are actuated by a coil or solenoid acting on a mechanism.

This coil is powered by the current between "phases" (between conductors) through contacts (command buttons, auxiliary contacts that maintain the coil after we have released the "start button" (memory) and contacts that are handled by the thermal-magnetic overload and differential elements: current difference between phases (protects the three-phase motor from running without one phase, while running or at the moment of starting, since for this reason the motor can "burn out" due to overheating).

The starter may consist of one or more contactors connected in a way that allows for a direct start, a resistor start, a transformer start, or a star-delta start.

These different contactor configurations are necessary depending on the motor's power and load during startup. Motors draw a high current, which may be so high that the electrical installation cannot handle direct starting. Or like when the engine cannot start because of the type of equipment it is pulling: a pump is not the same as an

air compressor, etc.

Motors over 5 HP should not have direct start. The contactors have thermal overload relays (and magnetic relays in some cases to protect against short circuits) that must be calibrated according to the maximum amperage the motor can handle.

Once calibrated, this rating should not be increased (otherwise the motor will burn out in an overload), and each time the relay trips, there is a reset button to reset the mechanism (after the thermal overload relays have cooled down).

Whenever a thermal overload relay trips, the problem must be investigated (motor braking due to mechanical overload, loss of a phase, worn bearings, friction in the bearings or motor rotor, etc.), since excessive resetting of the mechanism while the motor is overheated will cause it to burn out.

The starter contacts should be inspected and cleaned periodically (don't forget to replace the spark arrestors or spark eliminators), and all connections to the wires should be tightened (loose connections cause overheating).

Contactors (starters) are classified by the current or power they can handle and the frequency or number of starts or loads per hour they will be subjected to.

Currently, electromechanical starters are being replaced by fully electronic starters, which have no electric contacts. N**ot to be confused with frequency/speed inverters or drives.**

Instead, contact is made by a solid-state semiconductor (such as a transistor, called a thyristor in alternating current), which is controlled by an electrical signal to trigger or cut off the current.

This system also replaces star-delta starters, allowing electronic starters to control the starting current according to preset parameters in the control circuit.

Similarly, there are already electronic starters that control the current frequency, allowing alternating current motors, whose speed or RPM is constant if the frequency is constant, to be regulated to different revolutions by varying the frequency and the applied voltage (this is very convenient where it is necessary to regulate the

motor speed, such as in a fan, pump or compressor, saving electrical energy, since with traditional flow regulation power is lost (because regulation slows, diverts or returns the flow, now it simply manages the desired flow by varying the speed of the system).

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Programmers:

Programmers are electronic-electrical or electro-mechanical devices that control the sequence of operation of the various components involved in the boiler's functioning.

Once they begin their "program," they first turn on the fan to purge the gases, then ignite the pilot light (spark or gas and spark). They have a combustion-sensitive element (photocell) that allows them to "see" if the pilot or main flame has ignited. If this operation fails within the first few seconds, the programmer stops and can restart the process in smaller liquid-fueled boilers (if it repeats and still fails to ignite, it stops and sounds an alarm).

In liquid fuel boilers exceeding 700,000 kcal/hour (> 1 million BTU/lb) and all gas-fired boilers, there will be no automatic recycle or restart.

To restart, the boiler operator must press a "reset" button. If the main flame ignites within a certain number of seconds, combustion is established and monitored by the flame-sensitive element (a photosensitive element or photocell sensitive to infrared light, and ionizers or ultraviolet light sensors in the case of gas combustion; the response time—the time it takes to detect the absence of a flame—will depend on the size of the burner and the type of fuel).

Every programmer is the "brain" of the boiler control circuit, but it depends on the level controls and the pressure switches, thermostats, etc. that enable it.

Pressure switches:

We have seen in previous chapters how they are connected and what their function is. Their contacts allow the operation of programmers or flame controls (modulating, on/off, etc.).

Pressure switches control the operation of the programmer and should never be removed from the control circuit, as they are what shut down the boiler once it reaches maximum pressure.

Thermosets (temperature switches);

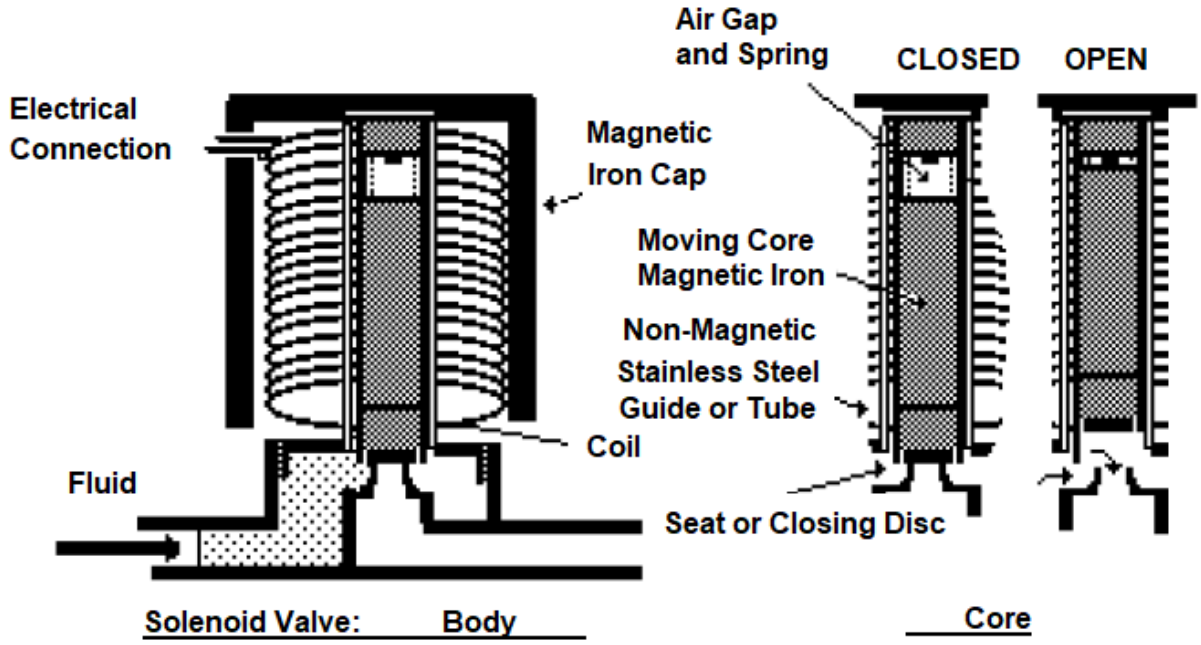
are generally used in hot water boilers or for temperature control of heavy liquid fuels (heavy fuel oil and heating oil).

Level controls:

We have also looked at level controls. These have contacts that enable the boiler's control circuits (programmers and manual control) so that they "cut off or turn them off" if the water level drops to the minimum permissible value.
They also control the feed pump contactor.

It is advisable to have **two level controls** so that each phase of the control circuit is interrupted in case of a low level.

It can happen with only one level control that if one of the control wires is grounded, the level control contact will not activate because it is "bridged" to ground. This reduces the danger posed by ground faults or short circuits in the wires.



Solenoid Valves:

Electrically controlled remote valves are generally solenoid valves. A solenoid (a coil with an internal metal core that acts as a magnet when current passes through it, usually alternating current; the magnet's pole will change with the current's frequency, but the mechanical attraction will remain the same) acts as a magnet, "lifting" or "pulling" a magnetizable iron stem (which moves inside a non-magnetic metal tube, usually stainless steel) attached to a valve "disc" (made of metal or Teflon, which seals against a seat),

allowing fluid to pass through.

These solenoid valves are used as pilot valves when the flow rate is very high, because the solenoid itself does not have enough force to lift a large valve "disc" (this also depends on the fluid pressure). This pilot valve acts as a control for another valve actuated by the same fluid.

The Electric Motor:

An electric motor can be direct current (DC) or alternating current (AC) (it is normally AC, and can be single-phase or three-phase). To define a motor, we must establish the voltage, the amperage (or power in kilowatts: kW or horsepower: HP), whether it is single-phase or three-phase (AC), the frequency in cycles per second (50 Hz or 60 Hz or Hertz), the revolutions per minute (RPM), the type of rotor and winding (induction: squirrel cage or wound rotor), the type of winding connection (star and/or delta), the type of construction (semi-open or closed), the type of insulation (which defines the maximum operating temperature), the type of bearings, etc.

The important thing is that once it's running, it must be kept free of moisture, prevented from overheating (due to excessive amperage or load), and prevented from operating with abnormal vibrations (ensure it's properly aligned with the pump or equipment it drives).

Preventive maintenance

should be performed according to usage: such as measuring the amperage per phase (on 3-phase motors), checking the winding insulation and cleaning it (keeping it dry and dust-free), replacing the bearings at both ends of the shaft as needed, etc.

To prevent the motor from burning out due to overload, it must be used with a good contactor that has differential thermal protection (this protects the balance between phases; if a three-phase motor is left on two phases, it will overheat and its windings may burn out even with thermal protection; this should not be confused with differential ground fault protection).

Its fuses should be (generally time-delay class aM) as close as possible to the minimum amperage rating required.

When a squirrel-cage induction motor vibrates, and after replacing the bearings, dynamically balancing the rotor, etc., it continues to vibrate, the fault may be caused by a break or cut in the rotor's squirrel-cage bars (in this case, a new rotor, i.e., a new motor, must be installed, since replacement rotors are generally unavailable, and it is not possible to repair the bar outside the rotor's electrical circuit).

The starting method for a three-phase motor is very important, since at startup, if the rotor is not specially designed, the starting current can be up to five times or more than the nominal value.

For this reason, at certain power levels (generally above 5 HP), special electric starters are used. (In the past, rotors were wound and started with resistors placed between the rotor windings via slip rings with carbon brushes, which were short-circuited once the motor started. More modern rotors have a special construction within the squirrel cage itself to reduce the starting short-circuit current.)

If the rotors were not special, starters with resistors or transformers were used to limit the current in the line. It was also possible that if the motor could be connected in a star-delta stator winding, this effect was used in the starter (star-delta starting).

Since this last possibility is not available, meaning the motor is necessarily started directly by its voltage, it can now be controlled using electronic starters that limit the current on the line itself. This modern system is now used instead of starting resistors or transformers.

Not just any system can be applied; the load and type of mechanical load connected to the motor must be studied, as starting a pump, a fan, or a compressor is not the same.

Today, variable speed (RPM) of electric motors is achieved electronically (previously it was done mechanically or electrically, such as with wound rotors), but electronic frequency regulation, by varying the RPM of electric motors, has very important applications in fluid handling, since we can establish the electrical power necessary for the flow and pressure conditions of the fluid, saving a lot of electrical energy and many mechanical

elements that are no longer needed.

With these regulation systems, induced draft and forced draft (primary and secondary) can be automatically controlled, seeking the best operating conditions for an appropriate response to changes in steam pressure and flow rate, maintaining optimal combustion conditions.

However, the converters do not regulate from 0% to 100%. In the first part of the regulation, modulating motor-driven "shutters" must be used to cover the area that the converter does not cover (approximately 0% to 30%).

For example, a wood-fired boiler can maintain combustion negative pressure by controlling the induced draft RPM and maintain steam pressure by controlling the RPM of the fans below the grate (primary and secondary).

Or, in small boilers,
the motors can be controlled directly with the steam pressure and an electronic controller for each motor, controlled by a controller with independent outputs. **This controller allows for the adjustment of all PID parameters (proportional to the signal, integral to the deviation, and derivative to the rate of change of the signal) and/or manual control of all or each of the controllers** (something unthinkable until a few years ago, since it saves electrical energy and achieves very good control if the PID settings are properly adjusted).

This can be improved by controlling the secondary air intake using an oxygen meter in the chimney that regulates excess air, thus varying the RPM of the secondary fan.

Let's look at a basic boiler control system:

This system can be both AUTOMATIC and MANUAL. Both systems should have a maximum pressure limit set by a pressure switch (a standard control pressure switch and a maximum pressure limit switch with manual reset).

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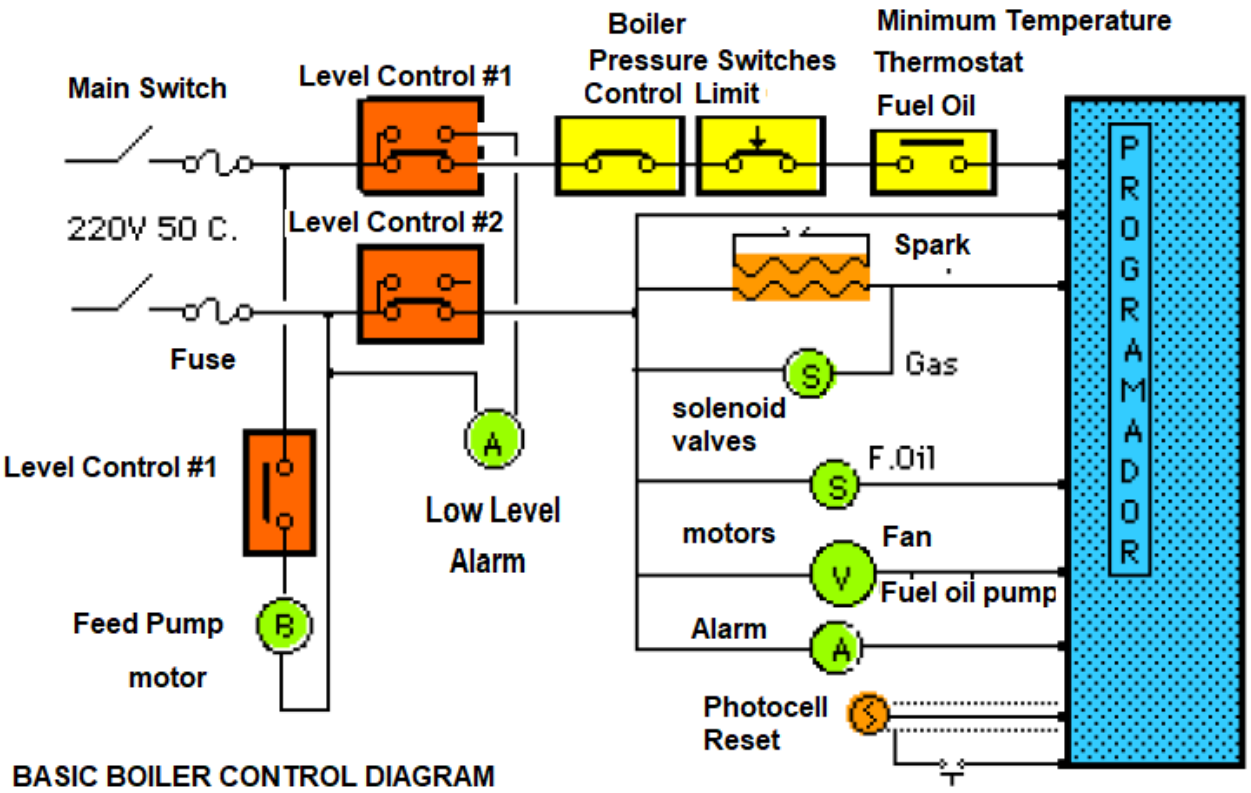


BASIC BOILER CONTROL DIAGRAM

In this case, we draw a diagram of an automatic circuit without MANUAL control.

This basic diagram lacks the fuel oil heating system, the power circuit for the motors, the lights and audible alarms indicating faults and operation, and manual ignition, etc.

It shows the bare minimum for the operation of a boiler with a single-flame burner and two level controls (the second is a safety feature in case the first one fails).

The programmer:

generally has a function that repeats a second start attempt if the first one fails due to a lack of flame detection. If it fails a second time, it will shut down and an alarm will sound (gas burners, including those using higher-power liquid fuels, will not have a restart cycle if ignition fails; the burner will remain locked until the boiler operator resets it).

To restart the cycle, the "reset" button must be pressed, which resets the programmer for a new cycle. It has a thermostat to prevent operation with cold fuel oil: this avoids poor atomization (resulting in combustion that would foul the boiler and also make ignition difficult, causing "pops" or "pulsations" in the firebox).

Electrical Maintenance:

A good practice is to keep the control panels clean and free of dust and moisture. Test at least once per shift (6 or 8-hour shifts) that the level controls shut off the burner when fully purged (simulate a low level with the burner lit).

Test the photocell's operation with the burner lit: cover it from the light and see if it shuts off the burner (then press the "reset" button).

As a precaution for the electrical system, keep the following on hand: several sets of fuses, spare solenoids for gas and fuel oil, and a new or refurbished programmer (that has been tested and is working).

To test the programmer,
a good practice is to connect it in the workshop with lamps as if they were the coils or loads.

This way, you can observe the lamps' operation when power is applied (remember to manipulate the photocell; that is, cover it initially until the gas and spark indicator lights up. If it "sees light," it does not enable the programmer).

This allows you to observe the ignition sequence and measure the timing of each stage (with the photocell covered, the fan first turns on: "sweep," then the gas and spark, uncover the photocell, and finally the fuel solenoid turns on.

Cover the photocell and observe the cycle repeating.
Leaving the photocell covered should trigger the alarm. Press the "reset" button, and the cycle should restart).

In some cases, it is advisable to have two pressure switches:
one for start-up and shutdown, and another for maximum pressure cutoff in case the first one fails.

It is recommended that this pressure switch be manually resettable, meaning that if it activates, the boiler will not restart until the operator resets it by pressing a "reset" button.
NEVER FIT AUTORESET PRESSURE SWITCHES

If the high-pressure cutoff switch fails, only the safety valves will act, releasing the pressure to the atmosphere.

For this reason, the safety valves must be of adequate quality and size so that each one is capable of releasing all the generated steam, with a minimum of two per boiler.

Solenoid valves must be kept clean and dry externally.
Remember to replace their metal cap or cover, as it is essential for proper operation (it forms part of the magnetic circuit that acts on the stem; not only will the valve lose actuation force if it is not covered, but in alternating current applications, the coil will overheat due to excessive current flow, as the self-inductance necessary to limit the current decreases).

Safety valves (not to be confused with relief valves, which are not the same), as well as other control and command elements, must be protected both inside and out, and should not be painted on days when the boiler room is being painted. Painting a control element or safety valve can cause it to malfunction or become "locked" by the paint when it gets into its internal mechanisms.

Cables passing through high-temperature areas must be mechanically protected (in conduit) and made of heat-resistant material. These cables should be replaced every few years (maximum of 5 years).

Never leave the control panel, level control valve covers, and pressure switch covers uncovered; they will accumulate dust and attract cockroaches. This dust and cockroaches can cause short circuits, jammed mechanisms, dirty contacts, etc.

The control panel should be kept clean and its terminals numbered, with schematic and diagrammatic drawings readily available so that malfunctions can be quickly diagnosed and repaired.

Every boiler should have a main electrical shut-off switch at the boiler room outlet so that in the event of a steam pipe rupture that could flood the room, or in the event of a fire, the power can be cut off.

All electrical components of the boiler must be properly grounded: motors, control panels, etc., to prevent live parts from being touched by someone (which could be fatal).

COMMENT:
The safety of a boiler is closely linked to its electrical and electronic controls (the entire operation of an automatic boiler depends on sensors: pressure switches, level controls, etc.) which, to function, must be connected by insulated conductors (wires insulated from each other and from ground, and capable of withstanding the high temperatures found in some locations).

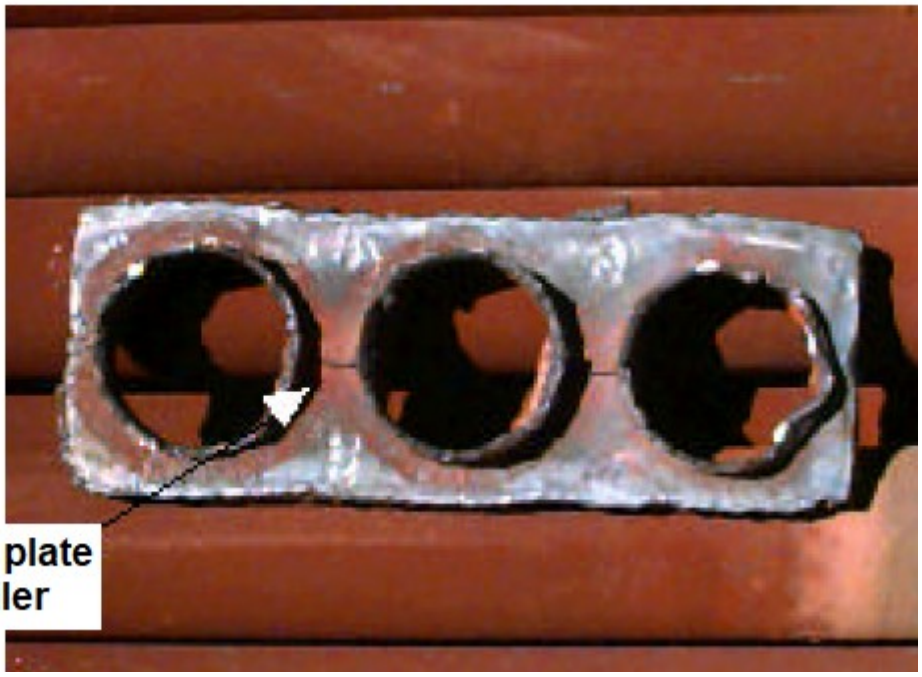
Any fault that could connect two wires together or a wire to ground (there is usually already a ground wire in the installation due to insulation failure in the electrical distribution system) can cause a

false reading of the control status and thus lead to a very serious malfunction.

If a pressure switch malfunctions and indicates a false reading, the burner may not shut off (in this case, only the safety valves can save us, as they open and maintain the pressure below the design limit).

However, if a level control indicates a false water level and there is no backup control, the low-level cutoff can be overridden.

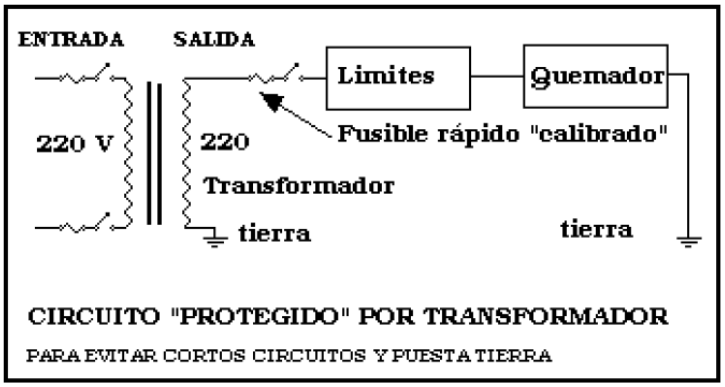
But even with two level controls, if the wiring fails at a point where both low-level cutoffs are overridden, the burner will remain lit without water, causing the boiler to burn out and creating a risk of explosion, especially if water suddenly enters when it is red-hot. Even so, the boiler can still be lost due to overheating and deformation.



Crack in the top plate of a fire-tube boiler

Part of the solution to these cable problems (both short-circuiting and grounding) is achieved by installing a power transformer at the control current input (a transformer with separate primary and secondary windings, not an autotransformer, to isolate the distribution system from the boiler control). One of the transformer's outputs is grounded, and a fast-acting fuse (set to the current rating) is placed on the live line. This way, if the cables short-circuit or ground, the fuse blows, and the burner is deprived of control

current (shutting down).



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With our father CWT (Carlos Walter Thomasset) and sister.
CIRCA 1972